CLAIMS

What is claimed is:

1. A method of compensating for disturbances that cause track shape irregularities on a disc in a disc drive during a disc servo-writing process, the disturbances substantially attributable to a nonrepeatable runout (NRRO) substantially caused by a cage frequency generated in a spindle motor in the disc drive, the method comprising steps of:

(a) determining a reference cage frequency;

(b) determining a feed-forward input signal based on the reference cage frequency; and

(c) feed-forwardly applying the feed-forward input signal to the servo-writer to substantially eliminate the track shape irregularities as track servo patterns are written by a servo-writing head operably connected to the servo-writer.

2. The method of claim 1 wherein the reference cage frequency determining step (a) comprises steps of:

(a)(i) writing a reference track that has minimal track shape irregularities;

(a)(ii) measuring a series of Position Error Signal values (PESs) using a reference position sensor, each PES value in the series corresponding to a sector on the reference track;

(a)(iii) determining a multiple series of PESs by repeating the step (a)(ii) over multiple disc revolutions, each series of PESs measured over one disc revolution;

(a)(iv) determining a series of repeatable runout values (RROs) for all sectors on the reference track, each RRO sequentially corresponding to a sector on the reference track, each RRO of a sector being an average of all PESs of the sector; and

(a)(v) determining the reference cage frequency of the reference track by subtracting the RRO of each sector from the PES of the same sector on the reference track.

3. The method of claim 2 wherein the reference cage frequency determining step (a) further comprises step of:

(a)(vi) phase adjusting the reference cage frequency of the reference track based on an angular displacement of the reference position sensor relative to the servo-writing head.

4. The method of claim 3 wherein the feed-forward input signal determining step (b) comprises steps of:

(b)(i) determining a calibration factor; and

(b)(ii) determining the feed-forward input signal based on the calibration factor and the phase adjusted reference cage frequency determined during the servo-writing process.

5. The method of claim 4 wherein the calibration factor determining step (b)(i) comprises steps of:

(b)(i)(1) writing an OD calibration track and an ID calibration track, the OD calibration track being located near an outer edge of the disc and the ID calibration track being located near an inner edge of the disc, both calibration tracks having minimal track shape irregularities;

(b)(i)(2) determining an OD cage frequency peak magnitude on the OD calibration track;

(b)(i)(3) determining an ID cage frequency peak magnitude on the ID calibration track; and

(b)(i)(4) determining the calibration factors for each sector on subsequent tracks to be written by the servo-writer based on the circumferential position of the corresponding sector, the radial position of the corresponding sector with respect to the OD and ID calibration tracks, and the OD and ID peak magnitudes corresponding to the radial position of the corresponding sector.

6. The method of claim 5, wherein an amount of adjusted phase of the phase adjusting step (a)(vi) is characterized by $D(\delta) = (f_{CAGE} * \delta) / f_{SPINDLE}$, wherein

$D(\delta)$ represents the amount of adjusted phase;

δ represents an angular displacement of the reference position sensor relative to the servo-writing head;

f_{CAGE} represents the reference cage frequency; and

$f_{SPINDLE}$ represents the disc rotational frequency.

7. The method of claim 6 wherein the calibration factor of step (b)(i)(4) is characterized by

$$Calibration\_Factor = \frac{1}{Pcs}\left(\frac{P_{COD} - P_{CID}}{r_o - r_i}(r_o - m * T) + \frac{r_o * P_{CID} - r_i * P_{COD}}{r_o - r_i}\right)$$ wherein

Calibration_Factor represents a factor for calibrating the cage frequency;

P_{CS} represents a peak reference cage magnitude;

P_{COD} represents the overall peak magnitude of the cage frequencies measured on the upper and lower OD calibration tracks;

P_{CID} represents the is the overall peak magnitude of the cage frequencies measured on the upper and lower ID calibration tracks;

r_o represents the distance between the OD calibration track and the center of the disc;

r_i represents the distance between the ID calibration track and the center of the disc;

m represents one of the cylinders (or tracks) numbered 0 to M; and

T represents the track density measured in the unit of tracks-per-inch (TPI).

8. The method of claim 7, wherein the feed-forward input signal determined in the step (b)(ii) is characterized by $p_{cf}(m) = Pcs(m) * (Calibration\_Factor)$, wherein

$P_{cf}(m)$ represents the determined feed-forward input signal for the cylinder (or the track) m; and

$P_{CS}(m)$ represents the cage frequency on the reference track while the cylinder (or the track) m is written during a servo-writing process.

9. A computer readable media readable by a computer and encoding instructions for executing the method recited in claim 8.

10. A disturbance removal system for compensating for disturbances that cause track shape irregularities on a disc in a disc drive during a disc servo-writing process performed by a servo-writer moving a servo-writing head, the disturbances attributable to a nonrepeatable runout (NRRO) substantially caused by a cage frequency generated in a spindle motor in the disc drive, the disturbance removal system comprising:

a reference position sensor;

a reference cage frequency determination module electrically connected to the reference position sensor;

a feed-forward input signal determination module connected to the reference cage frequency determination module, determining a feed-forward input signal based on the reference cage frequency; and

a servo-writing module receiving the feed-forward input signal from the feed-forward input signal determination module, while the servo-writing head electrically connected to the servo-writing module is writing servo patterns on the disc during the servo-writing process.

11. The disturbance removal system of claim 10 wherein the reference cage frequency determination module comprises:

a reference track writing module causing the servo-writing module to write a reference track that has minimal track shape irregularities on the disc;

a Position Error Signal (PES) measurement module that measures a series of reference PESs detected by the reference position sensor, each reference PES of the series sequentially corresponding to each sector on the reference track;

a repeatable runout (RRO) determination module that determines a series of RROs for all sectors on the reference track, each RRO sequentially corresponding to a sector on the reference track, each RRO of a sector being an average of all PESs of the sector; and

a reference cage frequency determination module that determines the reference cage frequency by subtracting the determined RRO of each sector on the

reference track from the PES of the same sector measured during the servo-writing process; and

12. The disturbance removal system of claim 11 wherein the reference cage frequency determination module further comprises a phase adjusting module that adjusts a phase of the reference cage frequency based on an angular displacement of the reference position sensor relative to the servo-writing head.

13. The disturbance removal system of claim 12 wherein the feed-forward input signal determination module comprises a calibration factor determination module that determines a calibration factor, wherein the feed-forward input signal determination module determines the feed-forward input signal based at least on the calibration factor and the phase adjusted reference cage frequency.

14. The disturbance remover of claim 13 wherein the calibration factor determination module comprises:

a calibration track writing module that writes an OD calibration track and an ID calibration track, the OD calibration track being located near an outer edge of the disc and the ID calibration track being located near an inner edge of the disc, both calibration tracks having minimal track shape irregularities;

an OD peak magnitude determination module that determines an OD cage frequency peak magnitude; and

an ID peak magnitude determination module that determines an ID cage frequency peak magnitude, wherein

the calibration factor determination module determines the calibration factors for each sector on subsequent tracks to be written by the servo-writer based on the circumferential position of the corresponding sector with respect to the OD and ID calibration tracks, and the OD and ID peak magnitudes corresponding to the radial position of the corresponding sector.

15. The disturbance removal system of claim 14, wherein an amount of adjusted phase of the phase adjusting module is characterized by $D(\delta) = (f_{CAGE} * \delta) / f_{SPINDLE}$, wherein

$D(\delta)$ represents the phase for adjustment;

δ represents an angular displacement of the reference position sensor relative to the servo-writing head on the disc;

f_{CAGE} represents the reference cage frequency; and

$f_{SPINDLE}$ represents the disc rotational frequency.

16. The disturbance removal system of claim 15 wherein the calibration factor is characterized by $Calibration\_Factor = \frac{1}{Pcs}\left(\frac{P_{COD} - P_{CID}}{r_o - r_i}(r_o - m * T) + \frac{r_o * P_{CID} - r_i * P_{COD}}{r_o - r_i}\right)$

where

Calibration_Factor represents a factor for calibrating the cage frequency;

P_{CS} represents a peak reference cage magnitude;

P_{COD} represents the overall peak magnitude of the cage frequencies measured on the upper and lower OD calibration tracks;

P_{CID} represents the is the overall peak magnitude of the cage frequencies measured on the upper and lower ID calibration tracks;

r_o represents the distance between the OD calibration track and the center of the disc;

r_i represents the distance between the ID calibration track and the center of the disc;

m represents one of the cylinders (or tracks) numbered 0 to M; and

T represents the track density measured in the unit of tracks-per-inch (TPI).

17. The disturbance removal system of claim 16, wherein the feed-forward input signal is characterized by $p_{cf}(m) = Pcs(m) * (Calibration\_Factor)$, wherein

$P_{cf}(m)$ represents the determined feed-forward input signal for the cylinder (or the track) m; and

$P_{CS}(m)$ represents the cage frequency on the reference track while the cylinder (or the track) m is written during a servo-writing process.

18. A disturbance removal system for compensating for disturbances causing track shape irregularities on a disc in a disc drive during a disc servo-writing process, the disturbances attributable to a nonrepeatable runout (NRRO) generated in the disc drive, the disturbance removal system comprising:

a servo-writer that performs the servo-writing process; and

means for determining a feed-forward input signal for the servo-writer based on a reference cage frequency.

19. The disturbance removal system of claim 18 further comprising means for applying the feed-forward input signal to minimize the track shape irregularities while track servo patterns are written on the disc by a servo-writing head operably connected to the servo-writer.

20. The disturbance removal system of claim 19 wherein the feed-forward input signal is determined based on a calibration factor.

21. The disturbance removal system of claim 20 wherein the reference cage frequency is determined based on PES values measured by a reference position sensor on a reference track, each PES value corresponding to a sector on the reference track.

22. The disturbance removal system of claim 20 wherein a phase of the reference cage frequency is adjusted based on an angular displacement of the reference position sensor relative to the servo-writing head on the disc.

23. The disturbance removal system of claim 22 wherein the calibration factor is determined for each sector on each track on the disc based at least on ID and OD cage frequency peak magnitudes and radial position of each sector with respect to ID and OD calibration tracks, the ID calibration track being located near an inner edge of the disc and the OD calibration track being located near an outer edge of the disc.

24. The disturbance removal system of claim 23 wherein a series of OD cage frequency peak magnitudes is determined from sectors on the OD calibration track, each OD cage frequency peak magnitude corresponding to a sector on the OD calibration track.

25. The disturbance removal system of claim 24 wherein a series of ID cage frequency peak magnitudes is determined from sectors on the ID calibration track, each ID cage frequency peak magnitude corresponding to a sector on the ID calibration track.

26. The disturbance removal system of claim 25, wherein an amount of adjusted phase is characterized by $D(\delta) = (f_{CAGE} * \delta) / f_{SPINDLE}$, wherein

$D(\delta)$ represents the amount of adjusted phase;

δ represents an angular displacement of the reference position sensor relative to the servo-writing head;

f_{CAGE} represents the reference cage frequency; and

$f_{SPINDLE}$ represents the disc rotational frequency.

27. The disturbance removal system of claim 26 wherein the calibration factor is characterized by $Calibration\_Factor = \frac{1}{Pcs}\left(\frac{P_{COD} - P_{CID}}{r_o - r_i}(r_o - m * T) + \frac{r_o * P_{CID} - r_i * P_{COD}}{r_o - r_i}\right)$

wherein

Calibration_Factor represents a factor for calibrating the cage frequency;

P_{CS} represents a peak reference cage magnitude;

P_{COD} represents the overall peak magnitude of the cage frequencies measured on the upper and lower OD calibration tracks;

P_{CID} represents the is the overall peak magnitude of the cage frequencies measured on the upper and lower ID calibration tracks;

r_o represents the distance between the OD calibration track and the center of the disc;

r_i represents the distance between the ID calibration track and the center of the disc;

m represents one of the cylinders (or tracks) numbered 0 to M; and

T represents the track density measured in the unit of tracks-per-inch (TPI).

28. The disturbance removal system of claim 27, wherein the feed-forward input signal is characterized by $p_{cf}(m) = Pcs(m) * (Calibration\_Factor)$, wherein

$P_{cf}(m)$ represents the determined feed-forward input signal for the cylinder (or the track) m; and

$P_{CS}(m)$ represents the cage frequency on the reference track while the cylinder (or the track) m is written during a servo-writing process.